Calculation of the weight coefficients of the criteria of the spatial factor and their interrelations with the investment objectives of the purchase of land plots

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Abstract. The article presents the results of the distribution of criteria according to investment objectives, which can serve as the basis for developing a mathematical model for assessing the investment attractiveness of land plots. Existing methods for assessing investment attractiveness were analyzed and a new assessment system was compiled. The criteria were ordered by calculating the weights using the T. Saaty Analytic Hierarchy Process, and the interrelations between the criteria and investment objectives were visualized using a graph. The classification and graph given in the study are able not only to determine the relationship between investment objectives and criteria, but also subsequently to form approaches to assessing the quality of the proposed classification.

1 Introduction

The methods known and described in the scientific literature for accounting for factors related to the spatial characteristics of both the evaluation object itself and its surrounding infrastructure do not allow to fully take these characteristics into account when determining the investment value of a land plot [1]. A number of methods for assessing the investment value of land plots were analyzed, taking into account the spatial factor, namely, the regression model [2], a neural network dynamic mathematical model developed by L.N. Yasnitsky and V.L. Yasnitsky [3], geostatic model [4], and methods of spatial interpolation [5-6].

In this regard, the development of an expert system that accounts for the influence of the spatial factor on the value of land plots is an important area of scientific and practical research. The development of this system is possible if there is a list of criteria, which is determined based on the given investment objectives.

When developing, it must be taken into account that each criterion may have a different relative weight depending on the investment goal.

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2 Materials and methods

To create an expert system, in particular, to form a technical assignment and requirements for the possibilities of its functioning, it is necessary to develop a knowledge base, which is a system of interrelations of investment objectives and the corresponding sets of criteria. The proposed strategy makes it possible to structure the existing spatial factors of the territories and form the requirements for the technical content of the expert system for assessing the investment attractiveness of land plots.

Conducting land valuation, it is necessary to take into account changes in the real estate market and spatial and economic factors that may affect the value of land. The proposed approach will make it possible to comprehensively account for many conditions and set a goal that determines the evaluation criteria. Due to changing factors, an investment valuation should be carried out regularly. The development of an expert system will be able to provide timely receipt of up-to-date information and speed up the process of choosing the most suitable land plot depending on the objective.

This article will consider what criteria should be taken into account depending on the investment objective, as well as the possibility of grouping land plots according to the level of investment attractiveness.

2.1 The concept of investment objectives and their main types

Investment objectives mean the tasks of investing money or capital with their further increase or preservation. For the effective investment management related to land plots, an appropriate assessment and forecasting of the value of real estate assets should be carried out. To achieve this goal, a number of criteria that affect the value of real estate assets should be accounted for and used for comparison with other real estate assets or land plots.

In order to determine which factors affect the value of a particular land plot and what criteria should be taken into account when evaluating it, it is necessary to understand the purpose of investing money in it. This implies the need to determine the list of investment objectives related to land plots.

The list of investment objectives for the purchase of land plots was formed based on the results of studying scientific sources and conducting problem interviews with representatives of industries related to the valuation and purchase of land plots. Information was received from specialists about the process of land purchasing, considering what should be taken into account, what factors affect the choice of land, what problems may arise when purchasing real estate. Land valuation is in demand by banks for secured loans, customer solvency analysis and other tasks. The result of interaction with specialists and the study of scientific literature was the definition of groups and types of investment objectives.

Three main groups of objectives were identified for investing in a land plot:

- Purchase of land for the purpose of resale.
- Commercial activity.
- Other.

Next, consider each formed group of goals.

Investments in the purchase of land for the purpose of their further resale can be considered in a different time period: short-term and long-term, as well as with and without additional investment.

As a short-term investment, one can consider the purchase and resale of the land at a higher cost due to the availability of information about future changes in the characteristics of the plot, as well as dividing the land plot into several, building utility infrastructure, improving the quality of the land, followed by the sale of the plots. In the long term, it is possible to consider buying a plot in a developing area, which is expected to become more attractive for living in the 5–10-year perspective, and the land value in it will increase. Also, one of the investment options is the lease of a land plot with the subsequent purchase and transfer of the category of land from one to another for subsequent sale.

The types of commercial activities carried out on land can vary widely. This may include construction of a shopping complex, a business center, a residential complex, etc. The listed options are mostly in demand inside the city, while outside the city commercial enterprises differ, representing gas stations, warehouses, industries, farms, recreation centers, tourist or agricultural companies. Moreover, commercial activity might be housing construction with subsequent leasing or sale.

The "Other" category defines other purposes that may arise when purchasing a land plot, such as the preservation of capital by purchasing a property, buying a plot with infrastructure or a house for personal purposes, or pledging a plot on a loan.

2.2 Overview of evaluation criteria

After the formation of the list of investment objectives, based on the data received from industry experts and the analysis of scientific literature, a set of possible criteria has been compiled that must be taken into account when assessing the value of land. Further, they were systematized into groups, each of which includes several criteria related in meaning. As a result, 12 groups of criteria were identified: value, presence of buildings on the plot, location, size, zoning, topography, soil, natural resources, access to utilities, environment, market, method of transfer/provision of plots. The result of the formation of criteria groups is shown in Table 1.

Table 1. Systematization and grouping of criteria.

Group No.	Criteria group	Criterion No.	Criterion
1	Value	1.1	Market
		1.2	Cadastral
2	Presence of objects on the plot	2.1	Utility lines
		2.2	Residential facilities
		2.3	Other facilities
3	Location	3.1	Administrative affiliation
		3.2	Transport accessibility:
		3.2.1	Time/distance to nearest highway
		3.2.2	Time / distance to the centers of attraction / influence of the district, to the city center
		3.2.3	Availability of public transport
		3.3	District infrastructure
		3.4	District prestige index
		3.5	Proximity to administrative centers
		3.6	Proximity to business centers
4	Size	4.1	Total land area
		4.2	Shape of the plot
5	Zoning	5.1	Category of plot
		5.2	Possibility to change the category of plot
		5.3	Commercial potential of the plot
6	Topography	6.1	Slope of the plot
		6.2	Land relief on the plot
		6.3	Amount of biomass
7	Soil	7.1	Type of soil
		7.2	Quality of soil
		7.3	Composition of soil

Group No.	Criteria group	Criterion No.	Criterion
8	Natural resources	8.1	Presence of a forest
		8.2	Presence of water sources
		8.3	Presence of natural minerals
9	Access to utilities	9.1	Sanitation
		9.2	Electrification
		9.3	Gasification
		9.4	Well
10	Environment	10.1	Proximity to the forest
		10.2	Proximity to water sources
		10.3	Proximity to sanitary protection zone
		10.4	Environmental conditions
11	Market	11.1	Legal aspects
		11.2	Demand for land
		11.3	Economic factors
12	Method of transfer/provision of plots	12.1	Lease
		12.2	Purchase

2.3 Proposed evaluation scheme

For each group of objectives, subgroups were identified, which are presented in Figure 1. Dividing the objectives into subgroups helps to consider each of them in more detail and determine the evaluation criteria that best fit each objective separately.

At the same time, general criteria were identified, which are important for each selected objective: value, buildings on the plot, market, and method of transfer / provision of plots.

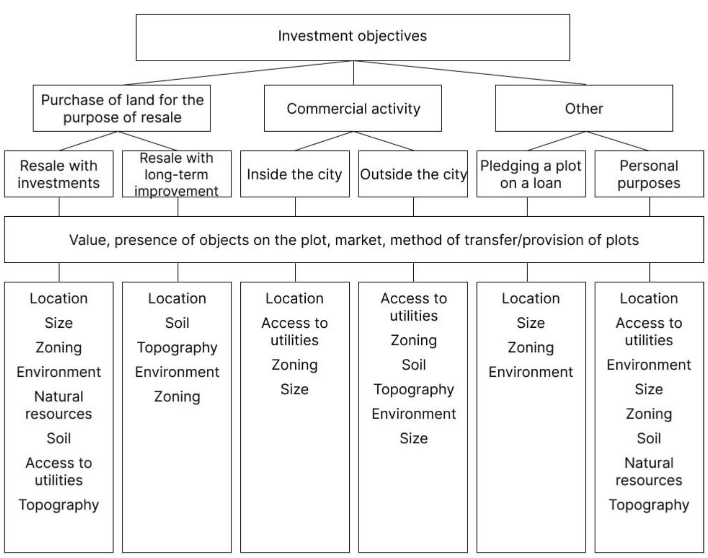

Fig. 1. Scheme of distribution of criteria for investment objectives

The purchase of land for the purpose of resale is divided into two subgroups - resale with an investment of funds immediately and long-term improvement of the characteristics of the plot. Location, zoning, and the environment will have the biggest impact on resale with improved plot characteristics. They are labor-intensive to change by investing, unlike, for example, access to utilities. Therefore, for this category, the criteria are built according to the degree of dependence on the amount of invested funds (from the smallest to the largest). For long-term improvement, it is necessary to take into account the possibility of investing in infrastructure development or its development near the plot without investments. This will increase the value of the land, which may eventually lead to a better resale. The most important criteria are location, soil, and topography - operations with earth masses on the plot are the most resource-intensive, so it is better to choose a plot with high rates according to these criteria.

The purchase of land for commercial purposes can be divided into subgroups on a territorial basis - within the city and outside it. It is assumed that the purchase of land in an urban area is intended for the construction of shops, malls, or business centers, so the most important criteria are location, access to utilities and zoning. Accounting for these factors will help to achieve a profitable investment of funds with the lowest financial costs. For the purchase of a plot outside the city, the determining condition is access to utilities, the provision of which requires large financial costs and approvals. Also, important criteria include zoning and soil, since most often land outside the city for commercial purposes is acquired for agriculture or housing construction. The choice of land for commercial use requires careful analysis and evaluation of many factors.

In the "other objectives" category, subgroups were identified - investing to preserve capital or buying a land plot for personal purposes. For capital preservation, location, size, and zoning are significant criteria, since they are the ones that affect the value of the land to a greater extent. Almost all criteria are important for purchasing land for personal use, but location, access to utilities and environment are of greatest interest according to an expert survey. This is due to the fact that the purchase of land for personal purposes does not always involve large financial investments immediately after the acquisition.

Thus, the distribution of criteria was carried out depending on the investment objectives and a scheme was developed, presented in Figure 1. The definition of criteria is important for comparing different options and choosing the best one based on objective data. To do this, it is necessary to ensure sufficient accuracy in the measurement and data collection.

GIS systems can become a convenient tool for evaluating criteria. They allow to analyze data on the location of objects on the surface and use this information to assess the value of land more accurately. Consider, using the example of calculating the distances from the land plot to the nearest schools, kindergartens, clinics, public transport, also the distance to Tver and Moscow according to the road graph shown in Figure 2, the distance to the Volga River and the distance to the M11 highway.

The distance to the Volga and to the M11 highway is Euclidean, that is, a direct distance, while other factors were measured using road graphs.

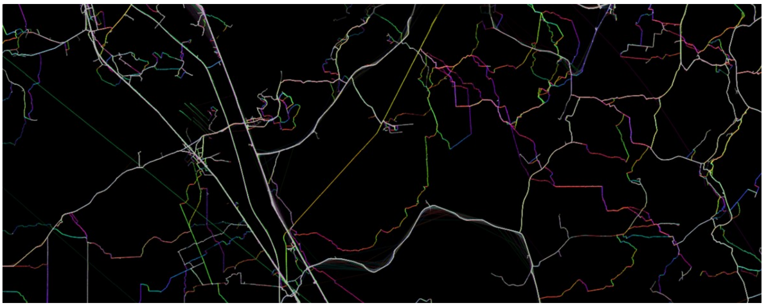

Fig. 2. An example of a road graph of a part of the Konakovo district of the Tver region.

Below, in Figure 3, there is an example of an image of a cadastral block with coordinates and distances to the selected objects.

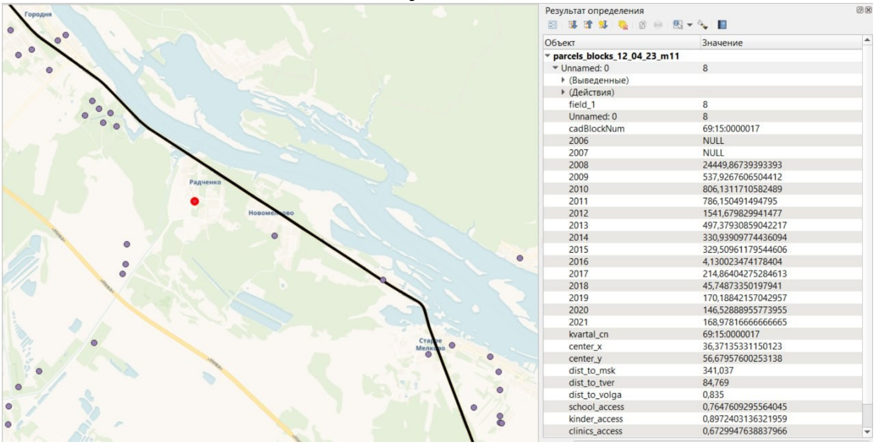

Fig. 3. Cadastral quarter with attributes.

All calculations can be performed using the Python programming language and additional Geopandas and NetworkX libraries, besides, in some cases, the osrm API was used to lay routes through the graph. The use of GIS makes it possible to assess the investment attractiveness of land plots more precisely in an automated form. The output data may be different criteria, depending on the investment objective. Figure 4 shows an example of what the output data might look like.

Ввод [3]:

```
cad_block = pd.read_csv('Output/parcels_blocks_12_04_23.csv')
cad_block['geometry'] = gpd.GeoSeries.from_wkt(cad_block['geometry'])
cad_block = gpd.GeoDataFrame(cad_block, geometry='geometry', crs = 'epsg:4326')
cad_block
```

Out[3]:

2012	2013	...	center_x	center_y	geometry	dist_to_msk	dist_to_tver	dist_to_volga	school_access	kinder_access	clinics_access	pt_access
4798.274806	2607.082323	...	36.710154	56.837660	POINT (36.71015 56.83766)	206.152	114.294	5.325	2.549365	37.155360	50.010299	2.457050
43.569003	520.963757	...	36.671494	56.719346	POINT (36.67149 56.71935)	202.168	99.852	2.539	29.549288	3.652297	66.916270	3.671678
NaN	NaN	...	36.834840	56.670675	POINT (36.83484 56.67068)	192.278	112.454	4.468	3.253354	3.157405	2.306587	2.064383
81111.588290	3866.107189	...	36.984239	56.695458	POINT (36.98424 56.69546)	205.611	171.095	1.329	7.425633	7.734787	7.480726	6.728862
NaN	149.629630	...	37.041077	56.612001	POINT (37.04108 56.61200)	212.393	164.314	9.429	6.437518	6.426449	17.705171	6.700075
...	...	...	...	...	...	...	...	...	...	...	...	...
NaN	NaN	...	36.708142	56.655320	POINT (36.70814 56.65532)	185.364	104.773	1.994	7.055769	6.661370	8.534393	0.738668
NaN	NaN	...	36.642577	56.613173	POINT (36.64258 56.61317)	192.121	94.179	1.624	1.843510	13.098453	2.342993	0.860310

Fig. 4. Code and data output file.

The definition of indicators for each criterion is important for their prioritization. After determining the exact values of the criteria, it is necessary to develop an assessment system for analyzing the investment attractiveness of land plots.

2.4 Determination of criteria weights

In order to arrange the criteria within the set for each subgroup of investment objectives, it is necessary to develop an approach to calculating the weights of the criteria. The determination of the weighting coefficients of the criteria is considered to be carried out according to the advanced analytic hierarchy process developed by T. Saaty. All criteria intended for the analysis of the project are evaluated by constructing a pairwise comparison matrix.

For a pairwise comparison of criteria, it is proposed to use an evaluation scale consisting of numerical indicators from 1 to 9 and their inverse values, which is shown in Table 2. Points are assigned by experts and reflect the degree of superiority of one criterion over another. If the criterion under consideration is less important than the other, then the inverse values are used, namely 1, 1/2 ... 1/9.

Table 2. Relative importance scale.

Value	Definition	Explanation
1	Equal, no difference	The expert finds it difficult to compare
3 (1/3)	Insignificantly more important	Criterion i is insignificantly more important than criterion j
5 (1/5)	More important	Criterion i is more important than criterion j
7 (1/7)	Significantly more important	Criterion i is significantly more important than criterion j
9 (1/9)	Fundamentally more important	Criterion i is fundamentally more important than criterion j

After the formation of the relative importance scale, the matrices are filled in by experts using the numerical values determined earlier. Experts are required to fill in only the upper part of the matrix (above the main diagonal), since the lower part of the matrix is filled with inverse values.

Table 3 shows a typical pairwise comparison matrix.

Table 3. Pairwise comparison matrix.

	Criterion 1	Criterion 2	Criterion 3
Criterion 1	$a_{11}=1$	a_{12}	a_{13}
Criterion 2	a_{21}	$a_{22}=1$	a_{23}
Criterion 3	a_{31}	a_{32}	$a_{33}=1$

In order to process the matrices obtained on the basis of expert opinions, it is necessary to determine the consistency index (CI), which reflects the presence of a logical connection between the evaluated criteria of investment attractiveness.

To calculate it, it is required to determine the maximum eigenvalue of the matrix and its dimension.

The calculation of the maximum eigenvalue *λmax* is calculated by formula (1):

$$\lambda_{max} = \sum_{j=1}^{n} s_j q_{2j} \tag{1}$$

With $s_j s_j$ – opinion column sum, $q_{2j} q_{2j}$ – the value of the first component of the normalized priority vector

The CI is calculated as follows (2):

$$\mathbf{CI} = \frac{\lambda max - n}{n - \mathbf{1}} \tag{2}$$

With λ max λ max – maximum eigenvalue of the matrix, n n – dimension of the matrix.

To correctly check the consistency of the corresponding matrices, it is also necessary to determine the CI of random matrices of this type (random consistency index - RCI).

To do this, random matrices of the same dimension as those under consideration are generated.

The obtained values are shown in Table 4 [7].

Table 4. RCI on a rating scale from 1 to 9.

Matrix order	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

In practical problems, the consistency of the pairwise comparison matrix may not be achieved since the expert's judgment cannot be expressed by an exact formula. When filling in the matrix, the expert uses estimates of the relative importance of preferences on an intensity scale from 1 to 9, which, without additional adjustment, can lead to inconsistency. The inconsistency of the pairwise comparison matrix can be caused both by the personal preferences of the expert and the degree of uncertainty of the object of assessment.

Since uncertainty is a property of the object of evaluation under study, the value of the consistency ratio (CR) can be considered an indicator of the quality of the set of expert evaluations. If the CR for the pairwise comparison matrix exceeds the threshold value, then this indicates a significant violation of the logic of judgments made by the expert when filling out the matrix. In this case, the expert is asked to revise the data used to construct the matrix in order to improve its consistency. A value below the threshold is considered acceptable, i.e., deviations of the elements of the matrix of paired comparisons from acceptable values are not so large as to noticeably violate the consistency. Based on the results of filling in the matrix, expert evaluations, as a rule, are subject to verification.

Next, it is required to determine the threshold value of the acceptable consistency of the matrix compiled on a scale of 1:9.

To do this, it is necessary to analyze the acceptable level of consistency of matrices by modeling, which consists in analyzing the values of the consistency ratio (CR) of the matrix with various deviations of expert estimates from the estimates corresponding to a fully consistent matrix (3):

$$\mathbf{CR} = \frac{\mathbf{CI}}{\mathbf{RCI}} \tag{3}$$

With the help of modeling, a certain value is determined that corresponds to the maximum CR for matrices that differ from the ideal one when any variable changes by one step. When the CR of the expert's judgment matrix becomes greater than the established threshold value, it is required either to re-interview the expert, or not to take this questionnaire into account when determining the result of the group examination. The remaining matrices can be used to calculate the criteria weights. For each row of the matrix is calculated by the formula (4):

$$x_j = \left(\prod_{j=1}^{n} a_{ji}\right)^{\frac{1}{n}} \tag{4}$$

With $a_{ji} a_{ji}$ – assessment of criterion j when compared with criterion i in the expert's judgment matrix, n – judgment matrix order.

Next, the weights themselves are calculated for each designated criterion (5):

$$v_i = \frac{x_j}{\sum_{j=1}^{n} x_j} \tag{5}$$

To obtain a consolidated average value using a group expertise, it is proposed to use a method that allows to conduct evaluations taking into account the different competences of experts.

After receiving all sets of criteria ratings from m respondents, for each j-th criterion, by calculating the expected value, the average value of the rating that was given to this criterion by all experts is calculated. The result is a vector characterizing the set of expected values of estimates for each of the n criteria (6):

$$\overline{\overline{v^{(A)}}} = \frac{1}{m}\sum_{i=1}^{m}\overrightarrow{v^{(l)}} = \left(\frac{1}{m}\sum_{i=1}^{m}\overrightarrow{v_1{}^{(l)}}, \dots, \frac{1}{m}\sum_{i=1}^{m}\overrightarrow{v_n{}^{(l)}}\right) = \left(\overrightarrow{v_1{}^{(l)}}, \dots, v_n{}^{(l)}\right) \tag{6}$$

With $\underline{v_j^{(A)}}\,\underline{v_j^{(A)}}$ – average value of criterion j, obtained by using the expected value.

Based on these calculations, we obtain average weights for a certain criterion and can prioritize their value for each investment goal. The use of a mathematical approach allows to create a structured system (Figure 5) of interrelations of investment objectives for the purchase of land plots and the criteria for their evaluation for an expert assessment of the investment attractiveness of land plots.

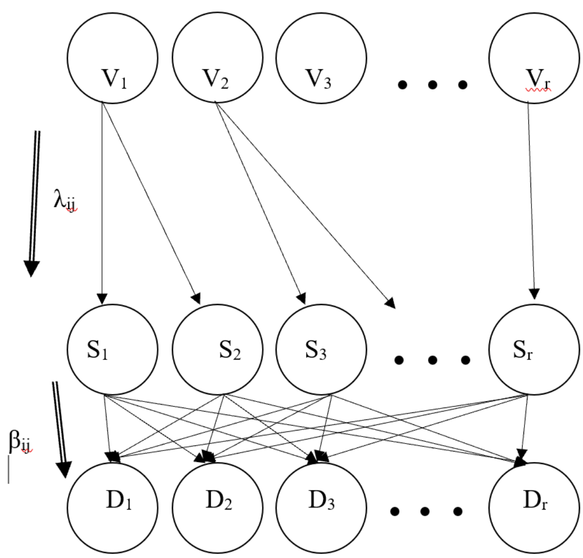

Fig. 5. The system of interrelations of investment objectives for the purchase of land plots and criteria for their evaluation.

The set of vertices V1, V2, V3, …, Vr of this graph is associated with a set of objectives groups. Objective means the objective of the investment in the land.

The set of vertices S1, S2, S3, …, Sr of the graph is associated with a set of subgroups of investment objective.

The set of vertices D1, D2, D3, …, Dr is the set of investment attractiveness criteria.

- λij –interrelations between groups and their respective subgroups of investment objectives.
- βij – interrelations between subgroups of investment objectives and a set of objects of investment attractiveness criteria.

As a result of creating the graph, the interrelations between the sets were visualized. Each investment objective corresponds to two subgroups of objectives that are associated with certain criteria – the interrelations are indicated as λij and βij. In the future, the graph can be completed with the values of weights for each edge.

3 Results

In this article, a list of investment objectives was defined, classes of investment objectives were formed, a list of criteria required for analyzing the investment attractiveness of land plots was selected and sets of criteria were formed for making calculations for each class of investment objectives. Moreover, the criteria are ordered by calculating weights using T. Saaty's analytic hierarchy process, the interrelations between criteria and investment objectives are visualized using a graph. The classification and graph given in the study can not only determine the interrelation between investment objectives and criteria, but also subsequently form approaches to assessing the quality of the proposed classification.

4 Discussions

The formation of a graph and the distribution of calculated weights of criteria will allow to systematize and reflect the interrelations between groups of input data for the development of a mathematical model – a set of criteria for evaluating land plots and a list of investment objectives.

This will help improve data analytics related to investing in land plots and will become an expanded theoretical basis for creating terms of reference for the development of an expert geographic information system for assessing the investment attractiveness of land plots. An expert geoinformation system can serve as an effective tool for appraisers when evaluating land plots. It should also be noted that the developed model can be used in various areas, including construction, agriculture, urban planning, and the formation of targeted investment programs. The use of an expert system can become one of the tools for territorial planning based on geoinformation technologies.

5 Conclusion

To account for the spatial factor in the models for estimating the investment value of land plots, it is necessary to use geoinformation systems (GIS) and other tools for analyzing spatial data. GIS allows the analysis of various spatial data, such as maps, satellite images, data on transport and commercial infrastructure, and others.

The results obtained make it possible to conduct further practical studies in order to identify possible levels of investment attractiveness for each class of investment goals.

Thus, in this article, the distribution of criteria by investment goals was proposed, which can serve as a basis for the development of an expert geoinformation system for decision-making in the field of territorial management problems.

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